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Interaction of clothing and body mass index affects validity of air-displacement plethysmography in adults

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Abstract

Objective: We determined the effect of clothing type on the validity of air-displacement plethysmography (ADP) to estimate percentage of body fat (%BF) and ascertain if these effects differ by body mass index (BMI).

Methods: The %BF by dual x-ray absorptiometry (DXA) and %BF, density, and body volume by ADP were assessed in 132 healthy adults classified by normal (N; 18.5–24.9 kg/m^2), overweight (OW; 25–29.9 kg/m^2), and obese (OB; 30–39.9 kg/m^2) BMIs.

Results: Compared with DXA, ADP underestimated ($P < 0.0001$) %BF from scrubs (SC) and t-shirt/shorts (TS) in N (11.4%; 8.6%) and OW (6.8%; 4.9%) BMI groups, respectively. ADP compared with DXA overestimated ($P < 0.0006$) %BF in the OW group (1.2%), but underestimated ($P < 0.0001$) it in the N group (2.4%). ADP also overestimated ($P < 0.006$) %BF in the OB group wearing spandex (SP; 4.8%), but not in those wearing SC (0.7%; $P = 0.10$) and TS (0.5%; $P = 0.22$) versus DXA.

Conclusion: All three clothing types showed significant error in estimating %BF with ADP compared with DXA in N and OW BMI. Use of spandex provided the least error and is the preferred attire to obtain valid body composition results when testing N and OW subjects. However, SP provided the greatest error in the OB group. Error in ADP %BF in OB was minimal in SC and TS and similar to the within-subject variability in %BF estimates with ADP. Thus, TS and SC are acceptable alternatives to SP in adults with excess body weight.

Keywords: Dual x-ray absorptiometry; Percent body fat; Body volume; Body density

Introduction

Air-displacement plethysmography (ADP) is a popular method for body composition assessment because it is safe and non-invasive. It also accommodates special populations, including children, the elderly, and the disabled, who have difficulty complying with the protocols of more established reference methods such as hydrostatic weighing and dual x-ray absorptiometry (DXA) [1].

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The Bod Pod, a commercially available instrument that uses ADP, estimates body volume under mostly adiabatic conditions but some air remains isothermal [2]. Factors that increase the volume of isothermal air, which is largely contained in the lungs, near the skin or hair, and in clothing, affect body volume determinations and, hence, body composition estimates and must be controlled [3,4]. To reduce the effects of isothermal air near the skin, individuals are advised to wear standardized, tight-fitting clothing, such as a swimsuit or spandex [5].

Limited findings suggest that the type of clothing worn in the Bod Pod can affect body composition estimates in adults. ADP significantly overestimated the body density and underestimated the percentage of body fat (%BF) of normal and overweight (body mass index [BMI] ranges of 18.5–24.9 and 25–29.9 kg/m^2, respectively) adults who wore hospital gowns compared with swimsuits or no clothing [4–6] or gym shorts, boxer shorts, or briefs compared with swimsuits [5,7]. In contrast, body density and %BF fat estimated with ADP were similar in normal and overweight women wearing minimal clothing (bra and panties) compared with swimsuits. Thus, clothing that is tight fitting or close to the skin may provide more accurate estimates of body density and fat than looser-fitting clothing.

However, individuals with negative body image, regardless of size, may not be comfortable wearing tight-fitting clothing or find it unacceptable. Adults with increased body size preferred more body coverage with clothing [8]. Similarly, a diverse sample of women with self-reported negative body image preferred less fitted clothing choices than other women with positive body image [9]. Availability of tight-fitting clothing for overweight and obese people also limits use of ADP in this population group [10], which accounts for >60% of adults in the United States [11].

Thus, there is a need to determine if tight-fitting clothing is needed to obtain valid body composition estimates with ADP in adults with excess body weight. In individuals selected on the basis of BMI, this study addressed the practical concern of selecting clothing schemes that are comfortable and feasible while maintaining the accuracy of body composition measurements using ADP. The purposes of this study were to determine the effect of scrubs, t-shirt/shorts, and spandex (reference) on the validity of ADP to estimate %BF compared with DXA and determine whether these effects were affected by BMI classification.

Materials and methods

Subjects

One hundred thirty-two healthy adult subjects were recruited for this cross-sectional study, with the goal of 44 subjects in the normal, overweight, and obese BMI groups [12]. Inclusion criteria were 1) age ≥18 y, 2) BMI ≥18.5 and <40 kg/m^2, 3) height ≤190.5 cm and weight ≤159 kg, 4) absence of chronic disease (e.g., diabetes) as determined by self-report, 5) women not currently pregnant or breastfeeding, 6) no medication use that could influence lung function, 7) no metal inserts or a pacemaker, 8) non-smoker and absence of a condition known to affect lung function (e.g., asthma), 9) willingness to wear spandex clothing during testing, and 10) no facial hair or willingness to shave facial hair on the day of testing.

Protocol

Subjects provided written informed consent and scheduled their testing appointment after receiving oral and written descriptions of the study protocol at a recruitment information meeting. During this time, height and weight were measured to group subjects into each BMI group. Subjects were instructed to abstain from caffeine, physical activity, showering/bathing/sauna within 4 h of testing; abstain from food for 2 h before testing; abstain from alcohol 24 h before testing; refrain from donating plasma or blood 2 d before testing; avoid wearing undergarments with metal (i.e., underwire bra); and bring a t-shirt and shorts on the day of testing. Subjects were shown an example of a cotton t-shirt/shorts ensemble. Although this ensemble was not standardized, subjects were instructed to refrain from bringing a shirt or shorts that was extremely loose fitting (i.e., shorts that hung down to the knees). T-shirts and shorts were not provided because we sought to determine if clothing comfortable to individuals with body image issues and/or excess weight could be used in place of tight-fitting clothing. Consequently, participants self-selected attire for minimal bulk but also to accommodate individual preferences for modesty and economic convenience (i.e., not requiring purchase of spandex/swimwear). All subjects complied with these guidelines. Female subjects were instructed to schedule an appointment during the 6–10 d of their menstrual cycle. Male subjects were reminded to shave facial hair or keep it trimmed short on the day of testing and to wear tight-fitting undergarments (i.e., no boxer shorts). A pretest questionnaire was administered to subjects on the day of testing to verify adherence to study protocol and document any changes (i.e., medication use) since study application. The study was approved by the institutional review board at the University of North Dakota.

Air-displacement plethysmography

Body volume and body density were estimated by using ADP (Bod Pod, model 2000A, Body Composition System, Life Measurement Inc., Concord, CA, USA). The device is a dual-chamber unit consisting of a testing chamber where the subject sits and a reference chamber where the breathing circuit, electronics, and pressure transducers are located [2]. A test system procedure was performed at the beginning of each testing day to evaluate the accuracy and precision of the volume measurements. Five consecutive measurements of the test cylinder volume were taken. Manufacturer criteria for an acceptable calibration of the five measurements were a mean difference of ±100 mL in cylinder volume and standard deviation ≤75 mL [13]. The within- and between-day coefficients of variation (CVs) in volume measurements of the cylinder were 0.08% and 0.31%, respectively. The Bod Pod was also calibrated using a three-step procedure before each subject entered the chamber. Details of the calibration procedure are described elsewhere [3]. The within-subject CV for ADP percent fat based on repeated measurements in our laboratory was 3.2%, which is within the range of within-subject CV (1.7–4.5%) for %BF from previous research [3]. Subjects were measured using ADP wearing three different clothing schemes without shoes or socks, i.e., hospital-style scrubs, t-shirt and shorts, and spandex t-shirt and shorts (men wore shorts only), as the criterion. Spandex was selected because it has been shown to be an acceptable alternative to a swimsuit and is indicated as a suitable alternative for testing by the manufacturer [5]. Scrubs and spandex clothing were provided. Subjects were measured first wearing scrubs, followed by t-shirt/shorts, and spandex to accustom them to wearing less clothing. A swim cap was worn with all clothing schemes and all shirts were tucked in to minimize volume and trapped air.

Subjects were instructed to enter the chamber, sit comfortably with hands resting on the lap, breathe normally, and minimize movement. Two trials, lasting approximately 50 s each, were performed with each clothing scheme, during which raw body volume was measured. The two raw body volumes were averaged if they differed by ≤150 mL [3]. A third trial was performed and the closest two body volumes were averaged if the difference in the first two raw volumes was >150 mL. In the event that the three raw body volumes were not within 150 mL, the unit was recalibrated and each trial repeated. During the last test while the subject was wearing spandex, thoracic gas volume was measured after body volume measurements. Instructions were provided and a practice simulation was conducted with each subject before the trial to familiarize him/her with the procedure. During lung volume measurement, subjects wore a nose clip, breathed through a tube and breathing valve, and performed a breathing maneuver similar to panting. Details of this procedure are discussed elsewhere [2]. A predicted thoracic gas volume, determined by Bod Pod 2.14 software was used to calculate body density and subsequently %BF when the subjects wore scrubs and t-shirt/shorts. To reduce the variability in body composition estimates associated with calculations from predicted versus measured lung volumes, we chose estimates from predicted lung volumes [2,14,15] for subsequent comparisons among all three clothing schemes. The Siri equation [16] was used to calculate %BF from body density.

Dual x-ray absorptiometry

Percentage of body fat was estimated from fat and fat-free mass measured by DXA (software version 11.2.1:7, QDR DELPHI-W DXA fan beam mode, Hologic, Bedford, MA, USA). Calibration measurements were performed each day before testing or if the machine was idle for ≥2 h between tests. The within-day CV ranged from 0.30% to 0.48% and the between-day CV ranged from 0.17% to 0.29%. The CV for total body fat from DXA was reported as 1–3% [17,18]. Four trained operators performed and analyzed scans. One operator performed standard DXA quality control assessment of all scans. Subjects wore scrubs during the procedure without shoes or socks and were supine on the DXA table during the whole-body scan. Scrubs were selected because they were uniform, lightweight, and had no metal.

Statistical analysis

Power analysis indicated that a sample of 132 subjects, with 44 in each BMI group, would provide 90% power to detect a mean difference of 2% body fat between methods

Table 1
Descriptive characteristics and body composition variables by gender and BMI*

Variable	BMI group					
	Normal		Overweight		Obese	
	Female (n = 26)	Male (n = 20)	Female (n = 22)	Male (n = 22)	Female (n = 21)	Male (n = 21)
Age (y)	36.1 ± 13.2^{a} (19.7–62.6)	34.9 ± 13.7^{a} (20.7–63.7)	49.9 ± 12.2^{b} (29.1–69.6)	39.8 ± 16.5^{a,b} (20.8–81.0)	44.3 ± 12.1^{b} (27.1–72.1)	49.5 ± 12.5^{b} (19.6–67.0)
Height (cm)	165.9 ± 6.3^{a} (156.4–180.1)	180.1 ± 6.5^{b} (165.4–188.9)	162.5 ± 5.8^{a} (151.3–175.9)	179.5 ± 5.6^{b} (167.5–186.9)	159.7 ± 4.5^{a} (153.0–166.9)	179.5 ± 5.9^{b} (166.8–189.7)
Weight (kg)	61.9 ± 6.3^{a} (49.6–77.5)	74.2 ± 7.3^{b} (52.6–82.1)	71.8 ± 5.8^{b} (63.1–83.9)	88.4 ± 7.0^{c} (73.9–101.6)	86.8 ± 7.1^{c} (72.0–98.7)	107.4 ± 10.0^{d} (95.9–131.5)
BMI (kg/m^2)	22.5 ± 1.9^{a} (18.7–24.7)	22.8 ± 1.5^{a} (19.2–24.9)	27.2 ± 1.3^{b} (25.1–29.8)	27.4 ± 1.3^{b} (25.3–29.7)	34.0 ± 1.9^{c} (30.7–38.1)	33.3 ± 2.7^{c} (30.1–39.3)

BMI, body mass index

*All values reported as mean ± SD (range). Means in the same row with different superscripts are significantly different (analysis of variance with Tukey-Kramer contrasts, $P < 0.05$).

within each BMI group. A within-subject standard deviation of 2.5% body fat and $\alpha = 0.05$ were used.

Errors in the percent fat estimates obtained using ADP relative to percent fat estimates obtained from DXA were calculated for each clothing type. Repeated measures analyses of variance using the Proc Mixed procedure in SAS 9.1 (Cary, NC, USA) were used to compare these errors, body volume, body density, and %BF from ADP among the three clothing schemes, and between gender and BMI groups. Tukey-Kramer contrasts were used for post hoc pairwise comparisons of means when appropriate. In addition, *t* tests were used to determine if percent fat estimation errors (as defined above) differed from 0 for each clothing scheme for each BMI group. The significance level was $P < 0.05$ for all tests. Data are reported as mean ± pooled standard error, unless otherwise indicated.

Results

Table 1 lists the physical characteristics of the subjects by gender and BMI classification. Because height differed by ±1–2 cm and weight differed by ±0.5 kg for four subjects between recruitment and the day of testing, two were reassigned to the normal group and two to the obese group from the overweight group. Significant gender by clothing type ($P < 0.0001$) and clothing type by BMI group ($P < 0.0001$) interactions were observed for body volume, density, and %BF (Table 2). Compared with spandex, ADP significantly underestimated body volume and percent fat in scrubs and t-shirt/shorts and significantly overestimated body density in scrubs and t-shirt/shorts for each gender and BMI group. Because a negative %BF is not realistic biologically, data from seven male subjects (six with normal BMI, one with overweight BMI) who had a negative %BF while wearing scrubs or t-shirt/shorts during ADP were excluded from the analyses to examine a more realistic comparison of body volume, density, and body fat among the clothing types. Significant differences in body volume, density, and %BF measured using ADP in scrubs and t-shirt/shorts compared with spandex by gender and BMI groups ($P < 0.0001$) remained; therefore, their data were included in all analyses.

Table 2 shows comparisons of %BF estimated by ADP in each of the clothing types compared with DXA. Significant interactions between gender and clothing type ($P < 0.0001$) and between BMI group and clothing type were found ($P < 0.0001$). The %BF estimated in scrubs using ADP was significantly underestimated for female subjects (−6.0 ± 0.34%; range −15.15% to 3.38%) and male subjects (−6.57 ± 0.36%, range −16.22% to 4.73%; Table 2) and subjects in the normal and overweight BMI groups (Fig. 1) compared with DXA. ADP also significantly underestimated %BF in t-shirt/shorts for women (−3.34 ± 0.34%, range −14.53% to 7.21%) and men (−5.33 ± 0.36, range −15.67% to 6.22%; Table 2) and for subjects in the normal

Table 2
Comparison of body volume, body density, and percent body fat for each clothing type by gender and BMI of subjects with a percentage of body fat greater than zero by ADP*

Variable/clothing	Female (n = 69)	Male (n = 56)	Normal BMI (n = 40)	Overweight BMI (n = 43)	Obese BMI (n = 42)
Body volume (L) by ADP					
Scrubs	71.422 ± 0.868† (46.269–97.938)	85.714 ± 0.976† (56.420–128.642)	64.460 ± 1.189† (46.269–76.978)	76.237 ± 1.095† (62.1767–95.785)	95.005 ± 1.127† (70.361–128.642)
T-shirt/shorts	71.687 ± 0.883† (46.326–98.404)	85.233 ± 0.921† (47.578–128.869)	63.628 ± 1.086† (46.326–77.242)	76.583 ± 1.101† (62.291–95.993)	95.170 ± 1.127† (70.689–128.869)
Spandex	72.206 ± 0.883 (46.839–98.994)	86.092 ± 0.921 (48.208–129.577)	64.310 ± 1.086 (46.839–77.974)	77.346 ± 1.101 (62.895–97.124)	95.790 ± 1.127 (71.189–129.577)
Body density (g/cm^3) by ADP					
Scrubs	1.0329 ± 0.0016† (0.9912–1.0863)	1.0604 ± 0.0018† (1.0084–1.0996)	1.0711 ± 0.0022† (1.0178–1.1155)	1.0472 ± 0.0020† (1.0063–1.0961)	1.0217 ± 0.0020† (0.9912–1.0592)
T-shirt/shorts	1.0270 ± 0.0016† (0.9887–1.0810)	1.0576 ± 0.0018† (1.0054–1.0945)	1.0679 ± 0.0022† (1.0113–1.1095)	1.0431 ± 0.0020† (1.0045–1.0945)	1.0191 ± 0.0020† (0.9887–1.0569)
Spandex	1.0179 ± 0.0016 (0.9824–1.0691)	1.0424 ± 0.0018 (1.0008–1.0791)	1.0505 ± 0.0022 (1.0049–1.0873)	1.0297 ± 0.0020 (0.9955–1.0791)	1.0101 ± 0.0020 (0.9824–1.0445)
Body fat (%) by ADP					
Scrubs	29.47 ± 0.73†‡ (5.67–49.39)	17.06 ± 0.82†‡ (0.15–40.85)	12.29 ± 1.00†‡ (0.15–36.34)	22.90 ± 0.92†‡ (1.62–41.92)	34.60 ± 0.93† (17.34–49.39)
T-shirt/shorts	32.17 ± 0.73†‡ (7.92–50.64)	18.28 ± 0.82†‡ (3.24–42.35)	15.03 ± 1.00†‡ (3.24–39.50)	24.78 ± 0.92†‡ (2.28–42.81)	35.87 ± 0.93† (18.36–50.64)
Spandex	36.48 ± 0.73§ (13.00–53.87)	25.06 ± 0.82‡ (10.47–44.61)	21.29 ± 1.00‡ (10.47–42.60)	30.90 ± 0.92§ (8.72–47.27)	40.13 ± 0.93‡ (23.91–53.87)
Body fat (%) by DXA	35.50 ± 0.56 (17.26–48.52)	23.44 ± 0.63 (10.59–36.13)	23.41 ± 0.77 (12.99–42.22)	29.68 ± 0.71 (10.59–42.77)	35.32 ± 0.72 (20.82–48.52)

ADP, air-displacement plethysmography; BMI, body mass index; DXA, dual x-ray absorptiometry

*All values reported as mean ± SE (range).

† Mean different from spandex ($P < 0.0001$).

‡ Mean difference from DXA ($P < 0.0001$).

§ Mean difference from DXA ($P \leq 0.005$).

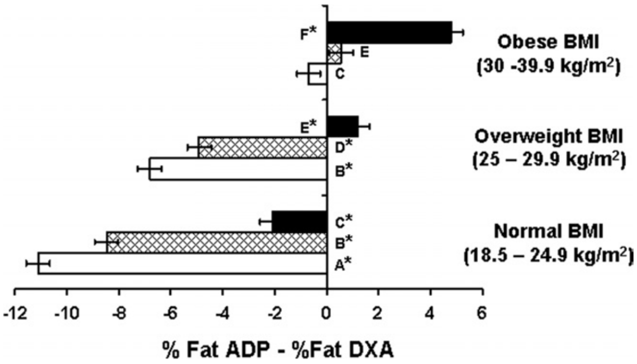

Fig. 1. Error in percent fat between ADP and DXA by BMI group and clothing type. Letters above bars indicate mean comparisons across BMIs and clothing types. Bars not sharing a common letter are significantly different ($P < 0.05$) by Tukey contrasts. Asterisks indicate that the mean error is significantly different from 0 ($P < 0.05$). Open bar = scrubs; cross-hatch bar = t-shirt and shorts; full bar = spandex. ADP, air-displacement plethysmography; BMI, body mass index; DXA, dual x-ray absorptiometry.

and overweight BMI groups (Fig. 1). The %BF was significantly overestimated by ADP in spandex for women (0.98 ± 0.34%, range −7.27% to 7.82%) and men (1.46 ± 0.36%, range −6.12% to 8.86%; Table 2) and subjects in the overweight group (Fig. 1), but underestimated among those with normal BMI (Fig. 1). In the obese BMI group, %BF was significantly overestimated by ADP in spandex compared with DXA. The %BF estimated by ADP was not different in scrubs and t-shirt/shorts and not different from DXA percent fat (Fig. 1).

Assessment of bias showed that the error of ADP in estimating %BF with subjects wearing spandex increased significantly ($R^2 = 0.303$, $P < 0.0001$) as body fat levels increased (Fig. 2A). For the entire sample (Fig. 2A), ADP overestimated ($P < 0.001$) %BF by 1.3% (95% confidence interval 8.7% to −6.1%). Errors in ADP estimation of %BF differed according to BMI classification. Although ADP underestimated %BF by 2.3% (95% confidence interval 2.3% to −6.8%), there was no effect ($P = 0.145$) of body fatness on error of ADP prediction of %BF compared with DXA (Fig. 2B) in the normal BMI group. In contrast, ADP overestimated %BF by 1.2% in the overweight BMI group (95% confidence interval 6.7% to −4.3%), and the error increased ($P < 0.05$) with %BF (Fig. 2C). ADP significantly overestimated body fatness (4.8%) in the obese BMI group (95% confidence interval 9.4–0.2%) but the differences in body fatness were not related ($P = 0.86$) to body fatness (Fig. 2D).

Discussion

Despite the increasing use of ADP to assess human body composition, there are limited data supporting the standardization of a practical and valid protocol for its use in groups with diverse body sizes. Although the research focus has been to identify proper attire to optimize measurement of body volume and estimate body composition, previous studies have compared the effects of different types clothing in groups without targeted analysis of differences within subgroups defined by ranges of BMI [4–7]. The present study addressed this limitation and determined the effect of common clothing types on ADP estimates of %BF, body density, and body volume and examined the validity of percent fat from ADP compared with DXA in adults selected for a range of BMI. The most notable finding was that %BF estimated by ADP in scrubs and t-shirt/shorts was not significantly different from DXA-determined %BF in the obese group. The magnitude of the errors in ADP-predicted %BF observed in the obese adults wearing scrubs (−0.7%) or t-shirt/shorts (0.5%) was substantially less than the reported mean errors in adult %BF determined with ADP and DXA, which range from an overestimation of 2% to an underestimation of 3% [3].

Controversy exists regarding errors in ADP estimates of body fatness compared with reference methods in obese adults. ADP compared with hydrostatic weighing underestimated body density and overestimated %BF of obese women [19], which is consistent with the findings of the present study. In contrast, ADP-derived estimates of %BF of obese adults were similar to values measured with hydrostatic weighing [20]. ADP compared with pencil-beam DXA underestimated body fatness of obese women by an average of 4% before and after weight loss [21]. In each of these studies, subjects wore apparently tight-fitting clothing (spandex or swimsuits) for the ADP procedure. Thus, differences in reference methods contribute to the lack of consensus in the literature of the validity of ADP to estimate body fatness in obese adults.

The increased error in percent fat between DXA and ADP in obese subjects in spandex may be related to the ability of ADP to estimate percent fat at higher BMI levels wearing similar clothing. In men with BMI ranges of 17–42 and 19–40 kg/m^2, ADP significantly overestimated %BF on the average of 2% compared with DXA, and the magnitude of the difference increased as body fatness increased [22,23]. Consistent with the findings of the present study, plots of %BF derived from ADP and hydrostatic weighing showed an overestimation of body fatness assessed by using APD in adults with body fatness exceeding 30% [4]. However, ADP significantly underestimated %BF (mean −2.6 ± 2.6%) compared with DXA in men (BMI 19–35 kg/m^2) and another group of men and women (BMI 20–36 kg/m^2, mean −3.0 ± 3.7%) [3]. Other studies have shown no bias in percent fat estimation in adults with similar ranges of BMI [20,24,25]. Each of these studies, however, only reported mean data, so it is unclear if the bias was selectively affected by one or more BMI classification group (e.g., normal, overweight, or obese). Furthermore, none of these studies was designed with adequate statistical power to evaluate the effect of BMI on the validity of ADP compared with a reference method. Thus, conclusions on the effect of body size or BMI await the results of further appropriately designed studies.

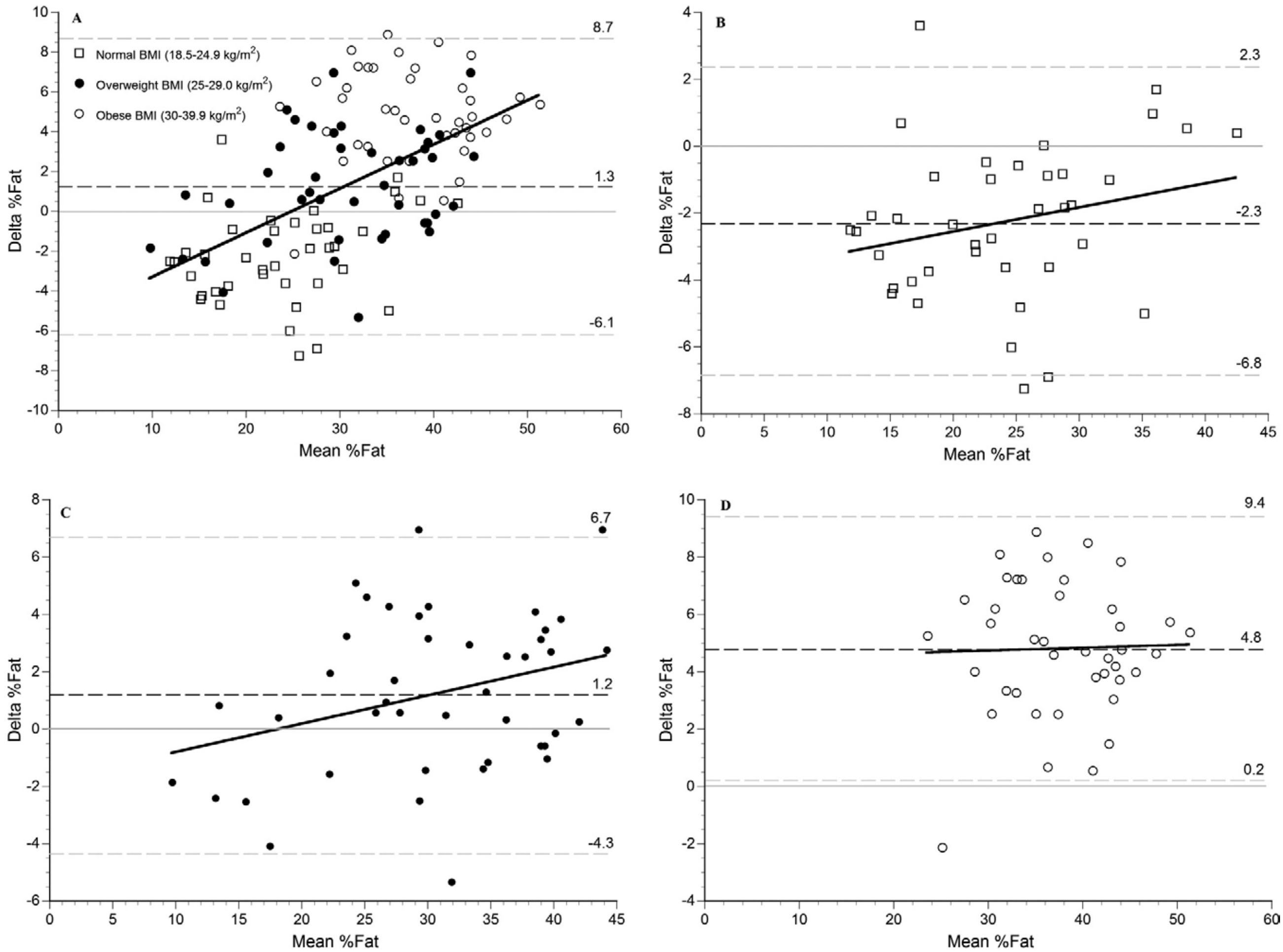

Fig. 2. Discrepancy between percent body fat (% fat) from DXA and ADP determined in spandex. Solid line represents the linear relation between mean differences in percent body fat (delta %fat = ADP-DXA) and mean body fat ([DXA and ADP]/2); dark abbreviated line is the mean difference and light abbreviated lines represents the 95% confidence interval. Data are presented for (A) the entire sample (n = 123, r = 0.551, $P < 0.0001$, Root mean square error = 3.17), (B) the normal BMI (18–25 kg/m^2) group (n = 39, r = 0.176, P = 0.145, RMSE = 2.29), (C) the overweight BMI (25–29 kg/m^2) group (n = 43, r = 0.275, $P < 0.05$, RMSE = 2.69), and (D) the obese BMI (30–40 kg/m^2) group (n = 41, r = −0.158, P = 0.86, RMSE = 2.37). ADP, air-displacement plethysmography; BMI, body mass index; DXA, dual x-ray absorptiometry.

Compared with DXA, ADP provided the closest estimates of percent fat in the normal and overweight BMI groups wearing spandex. Although %BF was significantly overestimated in the overweight group, this difference was small (1.2%) and less than the variability of repeated ADP measurements [3]. Percent body fat was significantly underestimated in the normal BMI group (−2.3%) compared with DXA and within the range of mean measurement error compared with DXA [17]. The magnitude of these errors in %BF is similar to the mean differences of 1–4% reported for bicycle shorts and cotton gym shorts, respectively, compared with a swimsuit as determined by ADP [5]. For cross-sectional assessment of body composition, the 2% difference in percent fat estimation with different methods will not be meaningful in characterizing groups, but will become more important when comparing longitudinal changes in %BF among methods [21].

The overall findings of the present study are consistent with an inverse relation between ADP-estimated %BF and increasingly loose-fitting clothing. Regardless of BMI group, ADP estimates of %BF increased significantly with more closely fitting clothing (Table 2). With looser-fitting clothing (e.g., scrubs), isothermal air trapped near the skin is more compressible, contributing to an underestimation of body volume, an overestimation of density, and an underestimation of percent fat [4,6] in each BMI group. Interestingly, in the obese versus normal and overweight groups, scrubs fit more closely to the body. Thus, we conclude that the isothermal air was minimized in this group, which resulted in estimates of %BF similar to the reference method.

A potential limitation of the present work is the use of fan-beam DXA as the reference method to assess body fatness. Although DXA-derived estimates of soft tissue composition are highly correlated with determinations from criterion methods, modest variations in absolute values of compositional variables by DXA have been reported [26]. Fan-bean compared with pencil-beam DXA was shown to underestimate percent fat 4–7% in subjects (children and adults) with body fat levels exceeding 23% [27]. Attempts to reconcile the errors of fan-beam DXA based on comparisons with reference methods have yielded robust correction factors derived from group data [26,28]. Application of any correction factor should be done with caution because the validity of the factor in different ranges of body size has not been demonstrated.

In conclusion, the findings of this study indicate that use of spandex in adults with normal and overweight BMI is appropriate to estimate body fatness with ADP because differences with reference methods are not biologically meaningful. In contrast, use of spandex in adults with obese BMI is not recommended because it yielded an error that exceeded the variability of the ADP method. Acceptable clothing alternatives for obese adults include scrubs and t-shirt/shorts because they provide minimal error in estimating percent body fatness compared with DXA and foster subject participation by reducing personal concerns with body image. Future research efforts should examine the validity of ADP to assess body composition changes and use multicomponent models to account for interindividual differences in composition of the fat-free body in different age groups and body sizes.

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